Demonstration and Assessment of Highway/Vehicle Safety Factors for Automated Followers in Truck Platoons

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IS4S, Huntsville, AL
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Supporters
Alabama Department of Transportation, Montgomery, AL
Peloton Technology Incorporated, Mountain View, CA
United States Army Ground Vehicle Systems Center, Warren, MI
Raven Transport, Jacksonville, FL

Proposal submitted in response U.S. Department of Transportation, Notice of Funding Opportunity (NOFO) Number 693JJ319NF00001: “Automated Driving System Demonstration Grants”

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AUBURN UNIVERSITY

OFFICE OF THE
VICE PRESIDENT FOR RESEARCH

March 21, 2019

Program Manager
U. S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Re: USDOT NOFO Number: 693JJ319NF00001 "Automated Driving System Demonstration Grants"; Title: Assessment of Highway/Vehicle Safety Factors for Automated Followers in Truck Platoons"

Dear Program Manager:

Auburn University is pleased to submit the referenced research proposal in response to USDOT Notice of Funding Opportunity (NOFO) Number 693JJ319NF00001. Dr. David Bevly of the Department of Mechanical Engineering will be leading a team effort for the project. Included in this work effort are four subcontractors and multiple consulting firms who have made a substantial commitment should this project be awarded. The subcontractors are University of Michigan at Dearborn (UMD), Integrated Solutions for Systems (IS4S), Mississippi State University (MSU), and ADAM CogTech. Dr. Bevly's team is a leader in autonomous truck platooning research having already successfully performed several on-road demonstrations. The National Center for Asphalt Technology (NCAT) at Auburn University is also committed to support this project by ***providing its 1.7 mile test track for long duration demonstrations at no-cost.***

Total estimated funding from USDOT is 4,974,820 over a period of 3 years for the project. Auburn University along with the subcontractors and consultants are committed to a total cost share of $881,739. AU's cost sharing in amount of $469,600, including $100,000 in cash will be for materials and supplies, Principal Investigators' salary, fringe benefits, and unrecovered indirect costs. ***Auburn University and NCAT are also investing over $1M toward truck automation at NCAT*** including the purchase of a truck for long-term autonomous operations and a new autonomous vehicle lab building that will directly benefit this project.

We appreciate the opportunity to work with DOT on this important project. If you have any technical questions regarding this project, please contact Dr. Bevly at (334) 844-3446. Post-award questions of contractual nature should be directed to Ms. Jennifer Keller, Senior Industry Negotiator at (334) 844-4977 or via email at iacagmt@auburn.edu. If any additional information is needed, please do not hesitate to contact us.

Sincerely,

Gene Taylor

Gene Taylor, Director of Sponsored Programs
For Dr. Jennifer Kerpelman, Interim Vice President for Research

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Part 1 – PROJECT NARRATIVE AND TECHNICAL APPROACH

Table 1.1- Summary Table	
Project Name/Title	Demonstration and Assessment of Highway/Vehicle Safety Factors for Automated Followers in Truck Platoons
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	Auburn University (Public Academic Institution)
Point of Contact (Name/Title; Email; Phone Number)	David M. Bevly Professor Department of Mechanical Engineering Auburn University, AL dmbevly@eng.auburn.edu (334) 844-3446
Proposed Location (State(s) and Municipalities) for the Demonstration	Alabama, Michigan, Mississippi
Proposed Technologies for the Demonstration (briefly list)	Automated Follower Truck Platooning: SAE Level 4 truck platoon follower behind an SAE Level 1 truck platoon leader, operating on both interstate highways for long haul and lower speed highways for short haul, addressing severe driver shortage.
Proposed duration of the Demonstration (period of performance)	10/01/2019 - 09/30/2022 (3 years)
Federal Funding Amount Requested	$4,974,820
Non-Federal Cost Share Amount Proposed, if applicable	$881,739
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$5,856,559

1.1. EXECUTIVE SUMMARY

In this demonstration, Auburn University has teamed with leading researchers and experts to assess key safety aspects of emerging truck automation systems, specifically truck platoons with a fully engaged driver in the lead vehicle followed by one or more trucks operating at SAE Level 4 without a driver. While deployment of Level 1 platooning in the U.S. is imminent, technology developers are moving much more slowly (if at all) to implement Automated Follower Truck Platooning (AFTP); at the same time individual Level 4 truck capability is being aggressively pursued by startups. AFTP offers an intermediate capability with similar (or better) economic benefits compared to Level 4 stand-alone trucks but with the vital safety advantage that human is operating the lead vehicle. Society benefits from this conservative safety philosophy while significant increases in freight capacity are gained from the combination of platooning and automated follower operations. Nevertheless, safety and operational aspects should be identified and investigated. The demonstration and research proposed here will hasten the safe deployment of AFTP by collecting/analyzing data and providing greater understanding in key areas of human dynamics, V2V communications, and freeway operations, across the Operational Design Domains (ODD) of limited access divided highway (long haul trucking) and short runs on local two-lane highways for operations such as forest to paper-mill. The driver shortage in both long- and short-haul operations are holding back the U.S. economy and AFTP is one potential nearer-term solution.

It is also important to assess AFTP performance factors over an extended operational period, and the Auburn NCAT track offers a highway-realistic closed-course environment in which a fleet of five trucks are running daily to accelerate pavement wear. Auburn-equipped AFTP trucks will be integrated into this fleet, along with full data collection and sharing, for this extended evaluation.

Importantly, the aim here is not to assess basic issues related to truck platooning itself (which has legitimately seen substantial study focused on Level 1 truck platooning) but on the specific aspect of highly automated platoon followers.

Employing highly capable truck platooning prototypes (built up based on FHWA, DOD, and DOE funding over the last five years), the Auburn team will collect test track and on-road data shared via a public portal, which can support Safety Analysis and Rulemaking within USDOT. Our proposed research and demonstration plan fulfills the Requirements set forth by USDOT, with physical demonstrations of Level 4 automation in differing operational environments, gathering and publicly sharing relevant data in near real time (working through the DOE National Renewable Energy Laboratory LIVEWIRE portal). During the course of the work, in addition to USDOT agencies, we will engage stakeholders in the trucking industry as well as state agencies (DOT as well as enforcement).

Rather than invest substantial development time in creating highly robust Level 4 follower capability – which is properly the domain of downstream commercialization efforts -- our approach will be to field follower trucks which can perform the nominal driving task at Level 4, at the same time relying on highly trained safety drivers to handle any unusual occurrences; this creates a highly feasible and sound technical approach which is not overly complex yet meets research and demonstration needs. As shown in the Part 2: MANAGEMENT, APPROACH, STAFFING, APPROACH; AND CAPABILITIES, the effectiveness of the management, technical approach, qualifications of the proposed project staff, and collective capabilities of the project team have been demonstrated during a steady stream of research, demonstration, and testing projects with DOT, DOE, DOD and commercial clients since the early days of truck platooning commercialization starting in roughly 2013. The trucks have operated extensively in test track environments, as well as on-highway in Alabama, Michigan, and Quebec, Canada.

In summary, given USDOT's intention to "fund a collection of projects that serve a variety of communities, including urban, suburban, and rural environments, and that serve a variety of transportation markets including freight, personal mobility, and public transportation," we fulfill the key aspects of freight operations in rural highways (long and short haul, high and low speed).

The Auburn team confirms agreement to negotiate and sign a mutually agreeable data sharing agreement with USDOT as a requirement for award.

1.1.1. Vision

The Auburn team's vision is to accelerate the transformation of road freight movement via practical automated driving solutions to solve critical safety and economic needs by demonstrating Automated Follower Truck Platooning in operational settings and providing data-based assessments of key infrastructure, technical, and human factors to optimize safety.

1.1.2. Goals

We aim to provide key insights to support preparation and commercialization for safe deployment of AFTP:

a. Inform state transportation agencies in preparing for AFTP deployment by assessing AFTP factors regarding interactions with other traffic, including potential safety improvements offered by intelligent connected infrastructure

b. Provide data-based recommendations to guide development of key performance requirements for AFTP in the areas of V2X communications, positioning, connected lateral/longitudinal control, and system robustness

c. Understand AFTP safety factors regarding lead truck driver responsibilities, driver performance, and driving experience

d. Assess issues regarding integration of AFTP into current road environments and business settings in which the driver shortage is acute: short haul, medium-low speed (example: forest to sawmill), long haul (interstate highway)

e. Inform engineering and commercialization of AFTP by working with stakeholders to assess trade-offs /interactions between technology, Operational Design Domain, deployment areas, freight operations, and regulations to outline early deployment scenarios

1.1.3. Objectives

This project will implement an effective surrogate technical implementation of AFTP for on-road operations as well as a fully automated follower capability for long term evaluation on a closed course. Based on this advanced technical capability, objectives are to:

a. Understand the degree to which infrastructure sensing/communications (V2X) at freeway interchanges can improve traffic performance of AFTP by providing data to the platoon to assist with maneuver decisions. The team will use computer modeling and simulation to complement real-world testing of AFTP on a highway-realistic section with an equipped interchange.
b. Understand key human factors aspects of platoon-lead-drivers to a) assess any increased physical/mental stress compared with normal driving situations and SAE Level 1 Platooning and b) assess value/need for continuous driver monitoring from a safety standpoint
c. Identify issues and opportunities relevant to AFTP fleet operations, based on extensive end-user outreach, supported by data created during demonstrations and long term operations in a highway-realistic closed-course trucking operation.
d. Create high level DFP system requirements that can support technical approaches for system developers and business planning for fleet operators and shippers
e. Facilitate effective and early deployment of AFTP by gaining feedback and sharing results via a Stakeholder Advisory Panel to be facilitated by industry experts

1.1.4. Work Areas

Per discussion of work areas on page 8 of the NOFO, our proposed demonstration will occur on both public roads and test tracks. Within USDOT's list of work areas for Federal funding under the ADS Demonstration Program, our demonstration and evaluation focuses on:

- (NOFO Item a.) Technologies associated with ADS;
- (NOFO Item b.) Advanced communication systems supporting safety and/or mobility, including vehicle-to-vehicle and vehicle-to-infrastructure interoperable communications that benefit ADS integration;
- (NOFO Item c.) Innovative mobility solutions that involve deployment of automated vehicles;
- (NOFO Item e.) Demonstration of shared interoperable fleet of automated vehicles; and
- (NOFO Item f.) Demonstration and validation of exchanges of data that can support and potentially accelerate the safe, efficient, and secure interoperable integration of ADS.

1.1.5. Key partners, stakeholders, team members, and others proposed to participate

Core Team

This demonstration project is led by Auburn University, including the GPS and Vehicle Dynamics Laboratory within Mechanical Engineering, Civil Engineering, the School of Forestry, and the National Center for Asphalt Technology. Partners are the University of Michigan-Dearborn, Mississippi State University Center for Advanced Vehicle Systems, IS4S (a vehicle systems integrator with extensive experience with operations and safety validation of truck platooning and automated vehicles), ADAM CogTec (startup in advanced driver monitoring based on artificial intelligence), plus expert consultants Richard Bishop (automated trucking expert, co-lead of the American Trucking Association's Technology and Maintenance Council Study Group on Automated and Electric Trucks), Michael Cammisa (former regulatory lead at ATA), Michael Britt (former Director of Vehicle Maintenance, UPS: United Parcel Service), and Jan Hellaker (retired from Volvo Trucks, former Director of DriveSweden, now U.S.-based truck automation consultant).

Other Participants

We are pleased to have broad support via the stakeholders noted below; these organizations will form the core of our Stakeholder Advisory Panel.

Our proposal has the support of the U.S. Army Ground Vehicle Systems Center (formerly TARDEC) to develop, test, and evaluate Highly Automated Vehicle Platooning, supported by several of our team members. As noted in their Letter of Support, GVSC will provide access to our team to use their automated platooning trucks to enable testing to be conducted with platoons of three or more trucks, as well as provide a military user viewpoint.

Alabama DOT and Mississippi Economic Development Agency have expressed strong support, noting that this project has the potential to accelerate deployment of AFTP and thereby increasing the freight capacity of existing infrastructure and economic activity. These agencies will participate on the Stakeholder Advisory Panel.

In addition to our internal experts, the trucking industry will be represented by Raven Transport (long haul) and East Alabama Paving, Inc. (EAP) (short and long haul). EAP will provide access to tracking and other data on their trucks. Both fleets will also participate on the Stakeholder Advisory Panel.

Peloton Technology will provide perspective to the Research Team based on their extensive experience (technical and human factors) in commercializing Level 1 Driver Assistive Truck Platooning.

1.1.6. Issues and challenges to be addressed

a. On-road operations, by their nature, will have variability in terms of weather and other traffic. This could make it challenging to collect sufficient data without confounding factors. This will be addressed by careful experimental design plus close coordination with our supporting DOT partner. Additionally, having full control of the Auburn NCAT truck allows for more reliable data collection under controlled scenarios as well as for long term testing.

b. Given the driver shortage generally, it may be challenging to find available CDL drivers. Working with our industry partners, we can mitigate this risk by possibly pulling from within their driver pool. Additionally, Auburn NCAT employs several CDL drivers who can be made available.

1.1.7. Technology(ies) that will be demonstrated to address the issues

To address the issues of interest to USDOT, Automated Follower Truck Platooning will be demonstrated , i.e. a SAE Level 4 truck platoon follower behind an SAE Level 1 truck platoon leader, operating on interstate highways for long haul, lower speed highways for short haul, and extended operations in a highway-realistic closed-course trucking operation (NCAT). Data will be publicly shared for these demonstrations. The project will implement an effective surrogate technical implementation of AFTP for on-road operations as well as a fully automated follower capability for long term evaluation within the NCAT closed-course trucking operation.

1.1.8. Quantifiable Performance Improvements

a. We will assess safety performance parameters for the AFTP lead driver, in terms of physical stress, attentional allocation, and cognitive effects. Employing the ADAM driver impairment countermeasures, safety performance improvement will be quantified.

b. We will prove the concept and quantifiably assess the potential for a smart highway interchange, equipped with roadside sensing and V2X communications, to sense and broadcast trajectories of vehicles on the merging ramp to the AFTP system, thus allowing the AFTP driver and overall system to adapt appropriately to enable smooth merging for all traffic participants. Recommendations will be provided for use by FHWA and state agencies, as well as system developers.

c. We will assess and quantify performance enhancements (compared to SAE Level 1 platooning) of core technical subsystems (V2V, positioning, vehicle control, etc.) to provide recommendations and High Level System Requirements to guide implementation of AFTP.

1.1.9. Geographic area or jurisdiction of demonstration

The demonstrations will occur on interstate and local roads within Alabama and Mississippi, as well as the NCAT closed course track near Auburn, AL.

1.1.10. Proposed period of performance including a schedule for implementation and evaluation of the demonstration.

The proposed period of performance is three years, with the schedule for each year shown below.

Task #	Description of Task	Year1				Year2				Year3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Vehicle Preparation		■	■			■	■			■		
2	Safety Analysis Through Simulation	■	■			■				■			
3	Data Collection and Analysis			■	■								
4	Baseline Testing		■	■									
5	Pre-Launch AFTP Demo Platform						■	■			■	■	
6	Launch AFTP Platform							■				■	■
7	Traffic Interaction Study							■	■			■	■
8	Determine Edge Cases								■				
9	Generate Reports	■	■	■	■	■	■	■	■	■	■	■	■

1.2. Context- Current Status and Outlook for Truck Platooning

Trucking is essential to the U.S. economy. According to the American Trucking Associations, trucks move 10.5 billion tons of freight annually, which is nearly 71% of all the freight tonnage moved in the U.S [1]. ATA notes that over 3.6 million heavy-duty Class 8 trucks are operated by over 3.5 million truck drivers, burning almost 39 billion gallons of diesel fuel. However, there is a severe shortage of qualified truck drivers - the American Trucking Association (ATA) estimated a shortage of nearly 50,000 drivers in 2016, with projections that the shortage could increase to 175,000 by 2025.

First generation low-automation truck platooning is nearing commercial launch, promising significant reduction of fuel use. Highly automated truck platooning, which we term Automated Follower Truck Platooning (AFTP), will improve freight capacity as well as efficiency, adding a counterbalance to the ever-increasing driver shortage.

The following provides a brief overview of truck platooning and provides key distinguishing factors between Level 1 and Level 4 truck platooning. These factors motivate the proposed demonstration and research.

Fundamentals of Platooning

Regardless of automation level, truck platooning depends fundamentally on three technologies: "connected braking," Forward Collision Avoidance and Mitigation (FCAM), and disc brakes. Connected braking is enabled by secure vehicle-to-vehicle (V2V) communications between a leader truck and follower truck, so that braking and acceleration of the follower truck is synchronized with that of the leader truck, providing automated longitudinal control of the follower truck. Communications occur via 5.9 GHz Dedicated Short Range Communications (DSRC), which has been allocated for traffic safety use. In the future, Cellular-V2X may also provide adequate performance to support platooning. Vehicle-to-Infrastructure (V2I) communications is not required.

Working in conjunction with connected braking is the radar-based FCAM system, which enhances the driver/vehicle reaction in an emergency braking event. FCAM systems build upon Adaptive

Cruise Control (ACC), which uses radar to adjust the speed to match that of preceding vehicles and has been in use by truckers (and in passenger cars) for several years
Since 2015, FCAM systems have been mandated on all new heavy trucks in Europe.

Most trucks on the road today are equipped with drum brakes. Disc brakes have superior performance to drum brakes and are now widely present on new trucks. Disc brakes have shorter stopping distances, automated brake adjustment, and greater predictability /reliability due to reduced overheating and associated wear effects; this results in reduced uncertainty in braking performance thus allowing for safely operating at shorter inter-vehicle gaps.

When conditions on the road require normal or hard braking, information on the forward truck's braking sent via V2V communications causes the rear truck to also initiate braking in less than one tenth of a second. The systems also open up the inter-vehicle space to accommodate another vehicle cutting in between the two trucks, when needed. These capabilities are only one aspect of a layered safety and risk reduction approach being implemented in systems coming to market.

Regulatory Factors in SAE Autonomous Truck Platooning

SAE Level 1 platooning operations are compliant with existing Federal Motor Carrier Safety Standards and Federal Motor Vehicle Safety Standards. At the state level, following distance laws come into play. Figure 1.1 shows states in which commercial SAE Level 1 truck platooning is now allowed in some form; indications are that more states will provide this allowance in the near term. Based on USDOT data, Peloton Technology estimates 51% of freight miles within the U.S. are now in states that have approved commercial truck platooning.

Figure 1.1- Truck Platooning Commercial Allowance per State (Source: Peloton Technology).

With regard to truck safety inspection, the Florida DOT report noted that since the Level I North American Safety Inspection protocol used by State Police currently covers proper maintenance and function of brakes for the tractor-trailer combination, and SAE Level 1 platooning builds upon proper brake operation, current inspection protocols are sufficient for DATP.

While SAE Level 4 AFTP appears to be allowable under the Federal Automated Vehicles Policy 3.0, there is some uncertainty at the state level. The investigations and data from the proposed demonstration are aimed at providing crucial insights to USDOT and state agencies to assist in developing appropriate policy to ensure safety.

Driver Role in SAE Level 1 Truck Platooning and SAE Level 4 Automated Follower Truck Platooning

Driver responsibilities in SAE Level 1 platooning are straightforward. The lead truck driver drives normally, possibly using ACC if conditions allow. The rear truck driver is fully responsible for steering and monitoring/responding to the road environment, with the system providing longitudinal control. Additionally, the attentive rear truck driver plays an important role in addition to the platooning system: in the case of a possible passenger car cut-in between two platooning trucks, the rear driver's responsibility includes watching for traffic that may be seeking to change lanes and thus create a cut-in situation. The rear driver may choose to pre-emptively halt platooning to allow the intervening vehicle space to perform their desired maneuver. Alternately, if the situation develops more quickly, the rear driver is expected to detect the impending cut-in as the intervening vehicle approaches the lane boundary and initiate a braking response before the system registers an in-lane intruder vehicle.

The driver role for SAE Level 4 AFTP is quite different, with no driver(s) in the following truck(s). This creates greater responsibility for the driver of the lead truck, operating at SAE Level 0 or 1. To what degree is the driver under greater stress? What is the value of active driver monitoring in the overall safety approach? The proposed investigations and demonstration will result in valuable data to address these and other human factors questions.

Traffic and Infrastructure Factors in SAE Level 1 Truck Platooning and SAE Level 4 Automated Follower Truck Platooning

Traffic interactions regarding truck platooning have been studied conceptually but not empirically; however insights are expected from FHWA's Platooning FOT program beginning this year. A study funded by Florida DOT began with the premise that traffic must not be impeded by truck platoons in merging and de-merging at freeway interchanges. The study concluded that, for Level 1 platoon truck drivers, this is addressed by proper share-the-road behavior expected of all truck drivers. When traffic is merging, the leader truck driver assesses the situation and judges whether to brake for merging traffic or to maintain speed so that merging traffic can come in behind the platoon. A lane change can be done as well if space allows. Or, a follower driver may dissolve the platoon if other traffic needs space to merge. Therefore, the study recommended that SAE Level 1 platooning should be allowed "on any limited access, multi-lane, divided highway, with decisions to platoon on a particular road segment based on driver and system assessment of conditions (traffic, topography, work zones, weather), plus any guidance from road authorities." Further, that SAE Level 1 platooning should be allowed "on any lane currently allowable for trucks…. allowing drivers to choose which lane is best." Their conclusions were bolstered by observing traffic interactions during a 1,215 mile operational demonstration on the Florida Turnpike in 2017, which did not raise concerns for Florida DOT or the Florida Highway Patrol (the demonstration was conducted with Peloton Technology at inter-vehicle separations of 20 meters).

When considering SAE Level 4 AFTP, the lead driver can make assessments and maneuver as described above and the automated capabilities of the follower truck(s) can respond to traffic seeking to merge. Given the testing and safety protocols built into the development process by providers of SAE Level 1 platooning systems, it can be expected that safety is maintained in these situations for AFTP. However, given limited sight distance when approaching interchanges, it could be useful for the lead platoon driver to have fore-knowledge of traffic on the ramp seeking to enter the highway in the same time the AFTP is traveling through the merge area. Thus the proposed investigation into traffic interactions will assess the value of a "smart interchange" in which the infrastructure senses traffic on the on-ramp and communicates trajectories via V2X to the AFTP system for driver or automated system response, quantifying effectiveness of various strategies.

Commercialization of SAE Level 1 Truck Platooning and SAE Level 4 Automated Follower Truck Platooning

Based on published information and public comments by system vendors and OEMs, SAE Level 1 truck platooning systems are coming to market in 2019 in the U.S. Operations will predominantly consist of two trucks operating at separation distances of 12-20 meters (steady-state following distances of non-platooning trucks were found to average 50 meters in a 2016 USDOT study). Based on track testing by Auburn University and Peloton Technology, at a 12 meter inter-vehicle gap the lead truck reduced fuel use by 3% and the follower truck had a reduction of 10%. This FHWA-funded Auburn study concluded that "based on fuel economy improvements observed in testing, a strong business case exists for introducing this technology." Further, based on business case analyses by the American Transportation Research Institute within the same project, that "DATP operations are highly likely to be feasible for a substantial portion of trucking operations, and key fleets clearly see this value."

By contrast, the prospects for SAE Level 4 AFTP systems coming to market are uncertain, despite the advantages of both fuel economy and labor benefits. In the last several years, truck automation startup companies have begun to develop SAE Level 4 individual truck systems, with significant testing and commercialization activities underway. Furthermore, in early 2019 Daimler Trucks announced a significant investment in the SAE Level 4 individual truck space over the coming years, with other OEMs making similar moves. While these SAE Level 4 individual truck systems are promised for the near term, in reality it may take many years for this capability to come to market in significant numbers given the massive challenges of having an automated truck operating "on its own" across vast stretches of highway.

While the SAE Level 4 individual truck approach is similar in some ways to AFTP, there are important differences. For early deployment, automated followers in platoons are a key intermediate step, building upon a mature SAE Level 1 platooning technology and benefitting from a driver in the front truck applying human intelligence to unexpected situations and corner cases. Unique questions (technical, traffic, human) arising from AFTP operations will be investigated in the proposed work, providing extensive data to grow the knowledge base for both system developers and government agencies to accelerate deployment and reap the benefits of AFTP operations.

The potential user community for AFTP is large. Classic long haul highway trucking is the key market for SAE Level 1 platooning and will benefit from AFTP. However the driver shortage extends beyond long haul to local short haul truckers carrying a variety of goods. As one example, the shortage has been especially acute in the forestry industry in carrying timber and other biomass from forest to mills on relatively remote highways (which can be an ideal setting for early deployment). A recent trade press article based on a survey of loggers, foresters, mill managers, and industry executives noted that "labor, both logging and trucking… continues to be the big-ticket item," such that the industry is open to new technologies to address the labor shortage." The College of Forestry at Auburn University is a leading force in addressing these and other industry challenges. The proposed work will explore issues and define High Level System Requirements for both types of end users, working with our Expert Team plus the Stakeholder Advisory Panel.

1.3 GOALS.

Our proposed demonstration aligns with and/or satisfies the Goals contained in the NOFO, Section A.

a. Safety: USDOT seeks to fund projects that demonstrate and test how challenges to the safe integration of ADS into the Nation's on-road transportation system can be addressed.

> To support safe integration of AFTP, plus additional performance issues, extensive data will be collected and analyzed to provide insights on enabling technologies, driver performance, and traffic performance.

b. Data for Safety Analysis and Rulemaking: USDOT seeks insights relevant for safety and rulemaking priorities needed to remove governmental barriers to the safe integration of ADS technologies.

> The activities proposed here are structured to address safety and other performance issues at a generic level so that results can be applied to regulatory and commercial development of AFTP. The results of the Demonstration are not meant to provide specific design approaches but instead to illuminate and quantify issues and strategies.

c. Collaboration: USDOT has prioritized collaboration and stakeholder engagement, including State and local governments, universities and private partners.

> Ensuring the outcomes from the proposed work are relevant to USDOT rulemaking plus the deployment actors is a top priority for this team. To accomplish this, a Stakeholder Advisory Panel (SAP) will be established at the outset of the Demonstration project,

created and led by highly experienced industry experts on our team. Public sector involvement will include state DOTs, enforcement agencies, and economic development. Technology developers plus end users will play a key role to ensure investigations are grounded in practical factors. The SAP will meet multiple times, be provided the opportunity to experience AFTP directly, and asked to comment on draft deliverables.

1.4. FOCUS AREAS.

Our proposed demonstration and assessment aligns with and/or satisfies the Focus Areas contained in NOFO Section A, as follows:

a. Significant Public Benefit(s): Successful deployment of AFTP (including helping public agencies prepare) will allow the benefits of automated follower operations to come sooner due to human involvement in the lead truck, improving freight operations and enhancing the US economy.
b. Addressing Market Failure and Other Compelling Public Needs: at this time, technical development of AFTP does not appear to be a near-term priority for established industry players. While OEMs may eventually introduce AFTP this demonstration and resulting data can serve to accelerate the process plus clarify user needs. Vehicle industry investment into AFTP to serve short haul needs, such as forest to mill, is even less likely due to the small size of these types of markets. Evaluation of important gains that could be made via driver monitoring and infrastructure-to-vehicle communications will assist in the commercial deployment process.
c. Economic Vitality: accelerating the deployment of DFP through the data and knowledge gained in this demonstration addresses vital cost and capacity issues for freight movement in the U.S.
d. Complexity of Technology: our approach provides a limited capability SAE Level 4 system which emulates a full capability Level 4 DFP system; which allows discovery of key issues as early as possible, with efficient use of Grant funds. Long term operation and evaluation of full capability SAE Level 4 AFTP in a highway-realistic closed course provides the link to future commercial systems.
e. Diversity of Projects: demonstration and evaluation of AFTP is a nearer term solution which addresses long- and short-haul rural freight operations.
f. Transportation-challenged Populations: this focus area does not apply to professional truck drivers as much as it would to other domains. However, our human factors team will ensure accessibility within the bounds of Commercial Driver's License requirements.
g. Prototypes: The starting point for this work is highly mature truck platooning systems. Auburn SAE Level 1 platoon capable trucks were first developed in 2015 and have been extensively upgraded since then to approach SAE Level 4 capability; these trucks have been safety validated and extensively evaluated and demonstrated on test track and a variety of highway types.

1.5. REQUIREMENTS

Requirement	Fulfillment
Each demonstration must focus on the research and development of automation and ADS technology (per the SAE definitions), with a preference for demonstrating L3 or greater automation technologies;	In DTFP operations, follower vehicles are SAE Level 4
Each demonstration must include a physical demonstration	Physical demonstrations will occur on limited access divided highways, local highways, and a highway-realistic closed course track.
Each demonstration must include the gathering and sharing of all relevant and required data with the USDOT throughout the project, in near real time. The Recipient must ensure the appropriate data are accessible to USDOT and/or the public for a minimum of five years after the award period of performance expires;	We will collect and publicly share relevant data in near real time, working through the DOE National Renewable Energy Laboratory LIVEWIRE portal. We will remove sensitive CBI and PII before providing public access to project data, consistent with the public access requirements. The data will be accessible to USDOT and the public for a minimum of five years after the award period expires.
Each demonstration must include input/output user interfaces on the ADS and related applications that are accessible and allow users with varied abilities to input a new destination or communicate route information and to access information generated by the ADS;	Accessibility factors relevant to truck driving (professional drivers) will be addressed within the context of Commercial Driver's License accessibility requirements.
Each demonstration must address how the demonstration can be scaled to be applicable across the Nation to similar types of road environments, and include an outreach task to share demonstration status, results, and lessons learned with other jurisdictions and the public, in furtherance of technical exchange and knowledge transfer.	We accomplish this requirement via our Stakeholder Advisory Panel outreach task. Experts who will lead SAP activities are respected leaders in this field. Working directly with system developers and the user community will ensure our data and conclusions can support private industry in scaling to full commercial deployment. The door will be open to involvement from any interested state agencies / jurisdictions for participation. The key aim of the SAP will be technical exchange and knowledge.

Table 1.2- Requirements fulfillment table

1.6. APPROACH

1.6.1. High-Level Technical Approach to Implement and Evaluate the Demonstration

AFTP will be implemented on two Auburn-owned Peterbilt Class 8 tractors capable of L2 platooning including lane changes. The follower truck will have a safety driver (and co-driver) to emulate L4 operations. The Auburn NCAT track will be the prime facility for long term testing at a variety of gaps and multiple scenarios, with on-road demonstrations occurring on state and local highways in Alabama.

The following describes the tasks and their timing at a high level; further information is provided in technical narratives following.

TASKS

<u>YEAR-1</u>

<u>Broad objectives –</u>

- ✓ Establish and validate AFTP autonomy baseline
- ✓ Design/implement lead driver human factors analysis
- ✓ Identify high level performance requirements to pursue in three year grant period
- ✓ Advance underlying enabling technologies
- ✓ Determine safety boundary via simulation
- ✓ Traffic Interactions: based on literature review to identify research needs, define objectives, develop simulation approach, collect required field data for calibrating simulation models
- ✓ Define and implement data collection approach
- ✓ Establish Stakeholder Advisory Panel and gain initial inputs

Task 1.1 AFTP Demonstration Platform Preparation (Auburn, UMD, IS4S)

a. Prepare L4 vehicle platform (GPS, ACC, steer-by-wire, V2V, I2V)
b. Prepare comprehensive risk management approach
    i. Perform functional safety analysis
    ii. Develop Risk Management Plan, continually update based on findings
    iii. Implement E-stop and manual intervention protocol for Safety Driver
c. Implement data collection platform (GPS, CAN, V2X)
    i. Verify data integrity, plus data accessibility via Public Portal
d. Benchmark performance of full system on NCAT test track (500+ hours of operation)

Task 1.2 Prepare AFTP Lead Driver Human Factors Assessment (MSU, ADAM)

a. Document and agree complete set of Engineering and System Requirements for the Driver Monitoring System (DMS)
b. Complete experimental design
c. Define approach to equipment integration and data collection
d. Construct Lab-based Proof of Concept (POC)
e. Implement data collection System on lead AFTP vehicle
f. Conduct initial experiments and data collection on NCAT track

Task 1.3: Perform Preliminary Traffic Interactions Investigation (Auburn)

a. Conduct literature review to identify research needs (Months 1 – 4)
b. Select simulation software and perform preliminary simulations of connected infrastructure supporting platoon system in merges (Months 5 – 7)
c. Collect field data for calibration (Months 8 – 12)
d. Define and implement track/on-road data collection approach
e. Test AFTP in realistic roadway environment with/without connected infrastructure at merge points

Task 1.4: Launch Stakeholder Engagement Process (Auburn, Expert Team)

a. Recruit and form Stakeholder Advisory Panel
b. Hold initial workshop to identify key issues for user community (long haul and short haul)
c. Gain input to development of User-based High Level System Requirements to guide research

Task 1.5: Define System Performance Goals/Outcomes for Full Grant Duration (Full team)

a. Overall System performance requirements (headway time, road type, traffic)
b. Data recording requirements (type, rate, storage, security)
c. Operational requirements (vehicles, location, speed, traffic, number of platooning vehicles)

Task 1.6: Define AFTP Performance Improvements for Year 2 (Full team)

a. Sensors and Actuators
b. Lead driver evaluation and support
c. Safety System
d. Determine safety boundary through end-to-end high-fidelity simulation

<u>YEAR-2</u>

<u>Broad objectives –</u>

- ✓ Develop detailed test plan
- ✓ Develop end-of-Year 2 Go/No-Go decision table
- ✓ Execute the detailed test plan: Requirements testing
- ✓ Populate end-of-Year 2 Go/No-Go decision table
- ✓ Advance underlying enabling technologies
- ✓ Simulation to drive edge case testing
- ✓ Conduct experiments to assess AFTP lead driver human factors
- ✓ Develop simulation scenarios for evaluating the impact of truck platoons on traffic operations and safety at freeway merging and diverging areas
- ✓ Develop traffic control strategies to improve performance of truck platoons at freeway merging areas
- ✓ Initiate long term assessment of AFTP operations within NCAT test fleet

Task 2.1 Pre-Launch AFTP Demonstration Platform Testing (Auburn, UMD, IS4S)

a. Develop detailed test plan
    i. Test cases (requirements, test environments, test procedures, expected results)
    ii. Train and certify all drivers
    iii. Test schedule and logistics
b. Develop Go-/No-Go decision table
    i. Success metrics per requirement spec
    ii. Technology readiness level (TRL)
c. Requirements testing and analysis
    i. Overall system performance testing
    ii. Headway time / Road-type / Traffic
    iii. Sub-system performance testing
    iv. Positioning / Longitudinal / Lateral / Radio
    v. Data recording testing (Type / Rate / Storage / Security)

Task 2.2 Launch AFTP Demonstration Platform (Auburn, UMD, IS4S)

a. Decisions on Go-/No-Go (risk assessment / mitigation based on system performance, data integrity, operations)
b. Perform demonstration and collect data in long haul environment (highway)
c. Perform demonstration and collect data in short haul environment (similar to forestry operations on lower speed highway)
d. Begin long term operations assessment by running DATP Platform within NCAT pavement testing truck fleet (100+ hours of operation)
e. Analyze On-road Vehicle Performance Data to Identify Safety Factors

Task 2.3 Conduct Initial AFTP Lead Driver Human Factors Assessment (MSU, ADAM)

a. Design, supply, install and commission in-vehicle ADAM DMS
b. Sign-off in-vehicle ADAM DMS with all relevant partners
c. Perform physical/cognitive AFTP experiments relative to “normal” driving (MSU, ADAM), analyze results
    i. Conduct experiments and data collection on NCAT track and highway
d. Analyze On-road Vehicle Performance Data to Identify Driver Factors
e. Conduct driver interviews

Task 2.4 Conduct Traffic Interactions Investigation in the Field (Auburn)

a. Develop simulation scenarios (Months 13 – 17)
b. Calibrate simulation scenarios using field data (Months 18 – 19)
c. Implement sensing and I2V in merging environment on test track
d. Evaluate the impact of on AFTP merging with/without instrumented infrastructure (Months 20 – 21)
e. Develop traffic control strategies to improve safety and traffic flow of AFTP in merging situations (Months 22 – 24)

Task 2.5 Stakeholder Engagement Process (Auburn, Expert Team)

a. Hold 2nd Stakeholder Advisory Panel and Demonstrate AFTP Performance to Panel and USDOT
b. Provide interim results for stakeholder feedback and guidance for next round of experiments
c. Inform stakeholders of the data analysis to support and accelerate the integration of AFTP technologies into operations

Task 2.6 Determine edge cases (UMD / Auburn / MSU-ADAM)

a. Headway-time / Speed / Trailer / Load / Tires
b. Driver state

Task 2.7: Define AFTP Performance Improvements for Year 3 (Full team)

a. Sensors and Actuators
b. Lead driver evaluation and support
c. Safety System
d. Determine safety boundary through end-to-end high-fidelity simulation

YEAR-3

Broad Objectives –

- ✓ Develop guidance for operations and safety of truck platoons entering and leaving the freeway
- ✓ Complete evaluation of AFTP lead driver human factors
- ✓ Launch experiments assessing AFTP lead driver active attention management
- ✓ Continue long term assessment of AFTP operations within NCAT test fleet
- ✓ Deliver Final Report based on demonstration results and stakeholder input, addressing commercialization plus public agency factors.

Tasks

Task 3.1 Pre-Launch AFTP Demonstration Platform Testing (Auburn, UMD, IS4S)

a. Develop detailed test plan
    i. Test cases (requirements, test environments, test procedures, expected results)
    ii. Train and certify all drivers
    iii. Test schedule and logistics
b. Develop Go-/No-Go decision table
    i. Success metrics per requirement spec
    ii. Technology readiness level (TRL)
c. Requirements testing and analysis
    i. Overall system performance testing
    ii. Headway time / Road-type / Traffic
    iii. Sub-system performance testing
    iv. Positioning / Longitudinal / Lateral / Radio
    v. Data recording testing (Type / Rate / Storage / Security)

Task 3.2 Conduct Further Testing with AFTP Demonstration Platform Based on Previous Findings (Auburn, UMD, IS4S)

a. Update Risk Management Plan
b. Perform demonstration and collect data in long haul environment (highway)
f. Perform demonstration and collect data in short haul environment (similar to forestry operations on lower speed highway)
c. Long term operations assessment by running DATP Platform within NCAT pavement testing truck fleet (full time, 3500+ hours of operation)
d. Analyze On-road Vehicle Performance Data to Identify Safety Factors
e. Summarize progress based on Year 1 goals

Task 3.3 Complete AFTP Lead Driver Human Factors Assessment (MSU, ADAM)

a. Conduct AFTP experiments to evaluate active driver performance management
    i. Conduct experiments and data collection on NCAT track and highway
b. Analyze On-road Vehicle Performance Data to Identify Driver Factors
c. Conduct driver interviews

Task 3.4 Conduct Further Traffic Interactions Investigation in the Field Based on Previous Findings (Auburn)

a. Define specific strategies for optimum merging support to AFTP operations based on simulation plus field testing (Months 25 – 27)
b. Finalize recommended traffic control strategies to improve safety and traffic flow of AFTP in merging situations (Months 28 – 30)

Task 3.5 Stakeholder Engagement Process (Auburn, Expert Team)

a. Hold Final Stakeholder Advisory Panel and Demonstration of Enhanced AFTP Performance to Panel and USDOT
    i. Demonstrate AFTP system capabilities
    ii. Demonstrate performance and human factors results of Lead Driver assessment
b. Evaluate issues regarding deployment of AFTP in long haul trucking and lower speed short haul (forestry or similar use case)
c. Assess regulatory and State Agency factors
d. Provide final results for stakeholder feedback and guidance to support preparation of Final Report
e. Inform stakeholders of the data analysis to support and accelerate the integration of AFTP technologies into operations

Task 3.6 Deliver Final Report

a. Draft Report
b. Final Report based on USDOT comments

1.6.2. Narrative Descriptions of Task Activities by Each Team Member

AFTP Demonstration Platform Evaluation and Technology Enhancements

UMD’s proposed work has the following objectives:

A. Advance AFTP through physical testing – improve safety margins through increased radio network reliability
B. Advance AFTP through modeling and simulation – understand the safety envelope and edge cases

To achieve these objectives the scope of work has been broken down into phases. In the remainder of this sections each of phases is described in detail with the associated time-period, expected outcomes, and go/no-go decision metrics.

Phase 1: Testing - Baseline without I2V

Time Period: October 2019 - May 2020

Scope of work and work plan: The project team will provide a baseline safety performance of AFTP at the National Center for Asphalt Testing (NCAT) test track facility and Alabama public roads. UMD will provide radio network for V2V and V2X, and support baseline benchmarking.

Decision Metrics: The team is expected to achieve a level of safety performance in a two-vehicle leader/automated-follower configuration that justifies further controlled testing. Performance will judged against prior NCAT testing under a DOE fuel-efficient platooning contract in May-June 2019 and is based on the following two tables:

Vehicle Initial Speed		**Assumed Steady State Vehicle Deceleration**		**Maximum Permitted Stopping Distance from FMVSS No. 121**
(mph)	(ft/sec)	(ft/sec^2)	(g’s)	(ft)
20	29.3	18.00	0.56	30.0
25	36.7	18.00	0.56	45.0
30	44.0	17.50	0.54	65.0
35	51.3	17.00	0.53	89.0
40	58.7	17.00	0.53	114.0
45	66.0	16.80	0.52	144.0
50	73.3	16.80	0.52	176.0
55	80.7	16.80	0.52	212.0
60	88.0	16.80	0.52	250.0

Table 1.3- NHTSA standard for deceleration and stopping distances for trucks less than 70,000 lbs. (Gross Vehicle Weight Rating).

Requirement	Proposal	Basis	Relationship to Standards	Reason
Range (longitudinal & lateral)	Minimum 300m; 360 degrees around vehicle	CAMP – application tested in SPMD also calculation of range needed for DNPW	SAE J2945/1	The setting is based on the need to provide accurate and timely safety alerts. The setting was obtained by extensively testing commercially available equipment and automotive sensors in a wide variety of driving environments.
Range (Elevation)	At elevation angle of +10 degrees and -6 degrees	CAMP and BAH research and testing capabilities	SAE J2945/1	Same as above
Reliability	Packet Error Rate < 10%	CAMP and BAH	SAE J2945/1	Same as above
BSM Radio Channel	All BSM transmissions and receptions on 172 (safety-critical communications).	FCC rules.	SAE J2945/1	Same as above
Data Rate	6 Mbps	CAMP and BAH research – CAMP research shows PER degradation using 12 Mbps. BAH research indicates problems after 500m, also BAH test done under "open field" conditions.	SAE J2945/1 (one of the bitrates included in 802.11)	Same as above – Also Current developers support a 6 Mbps data rate. More data and testing is needed to change the data rate and determine if a changing rate can be used and support crash avoidance.
Transmission Frequency	10 times per second under non-congested conditions	CAMP – trade-off between long inter-packet delays experienced by V2V safety applications and heavy wireless channel utilization.	SAE J2945/1	Accepted among experts to support V2V crash avoidance
Staggering Transmission Time	Random transmission of BSMs every 100 +/- ms between 0 and 5 ms	Mitigate channel congestion if all devices transmitted at same time – CAMP and BAH research	SAE J2945/1	Due to accuracy of devices need to mimic the stagger experienced during SPMD to avoid message collisions to facilitate efficient channel usage

Table 1.4- Proposed NHTSA V2V communication requirement for DSRC-based BSM transmission.

Phase 2: Baseline with I2V

Time Period: June 2020 - September 2020

Scope of work and work plan: The trucks will be transported to testing sites in AL. All the trucks will be instrumented with National Renewable Energy Laboratory (NREL)'s data collection system.

Decision Metrics: The team is expected to achieve a better level of performance due the availability of I2V - Traveler Information Messages (TIM).

Phase 3: Simulation

Time Period: January 2020 - December 2021

Scope of work and work plan: Physical testing of trucks, even when done in test tracks, poses challenges. Simulation will be used to mitigate the underlying holes in physical testing. The exact testing environment will be modeled, including road networks, buildings, road signs, barriers, etc. Modeling and simulation will encompass both autonomous control as well as the V2X communication elements. Probabilistic trials will be run to benchmark average performance as well as its relative variance. *PreScan* and *TruckSim* will be the commercial software package used in these simulations.

Decision Metrics: The expected output of the simulation effort is performance measures:

- ✓ Time-to-collision as a function of vehicle speeds and following/headway distance, and
- ✓ Radio network performance as a function of platoon position and traffic

The key to validating the results of the proposed simulation is data acquisition and analysis during actual tests.

Phase 4: Data Collection and Analysis

Time Period: October 2019 - August 2022

Scope of work and work plan: The success of the testing and simulation efforts heavily relies on the ability of the trucks to gather and analyze data – both real-time as well as offline. Baseline data is vehicle state – not only of the host vehicle, but also other vehicles in the V2V network.

While knowledge of states of other vehicles in the network depends on data link reliability, that of the host vehicle state is independent of V2V communications and can be gathered by adequate instrumentation. The data acquisition system identified by the team is state of the art, and addresses the data needs for the proposed effort.

Decision Metrics: Data collection and analysis aids vehicle testing and simulation efforts. Continuous interactions between team members will occur to maximize the value of this component of the scope of work.

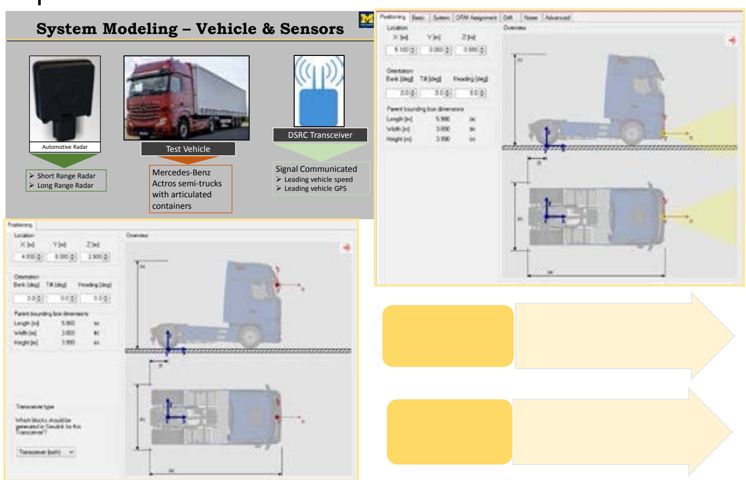

Figure 1.1- PreScan/TruckSim-based simulation

Phase 5: Continued Testing

Time Period: October 2020 - August 2022

Scope of work and work plan: One of the innovations of the proposed DOT project, is the year-round testing that is feasible.

Decision Metrics: Continuous testing aids controlled testing planned for NCAT. The team expects to improve significantly on the baseline testing performance described in Task 1. Each year the team expects to advance the follower autonomy level

Year 1: Autonomy Level 2 → Year 4: Autonomy Level 4.

Phase 6: DSRC – CV2X Comparison Testing

Time Period: October 2020 - August 2022

Scope of work and work plan: After establishing the Baseline, UMD wants to benchmark the performance of V2X radio network using DSRC versus CV2X. Specifically, the team will document whether these two technologies can complement each other.

Decision Metrics: This comparison will be made holistically and will use the performance triangle in Figure 2.

Phase 7: Final Demonstration – End of Work

Time Period: August 2022

Scope of work and work plan: At the end of Year 3, a DFP truck convoy demonstration will be held. This demo will showcase the progress achieved during the proposed three year project. The ultimate goal being Level 4 Autonomy capability for the follower truck(s).

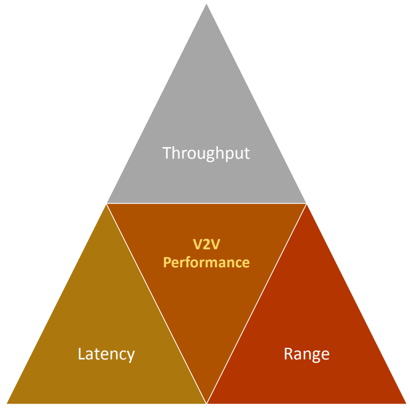

Figure 1.2- Performance metrics for comparing DSRC and CV2X.

Human Factors Evaluation of Lead AFTP Driver

Task: A Study of Driver Vigilance and Fatigue while Platooning

Background: Research has consistently demonstrated the connection between fatigue, vigilance, and safety for truck drivers (e.g. Boyce, 2016). The consensus is that additional research is needed to fully understand driver fatigue, and its connection to safety outcomes. The National Academies of Sciences, Engineering, and Medicine (2016) have published a report outlining the research needs related to driver fatigue and highway safety. The U.S. Department of Transportation has researched ways to reduce fatigue and improve safety outcomes (e.g. Dinges et al., 2017), and researchers have explored the efficacy of using various alert systems in the vehicles (e.g. Ferreira, et al., 2019).

Fatigue in truck drivers is multifaceted. Wise, Heaton, and Patrician (2019) conducted a meta-analysis of fatigue research related to long-haul truck drivers, and concluded that there are four primary dimensions of fatigue for this population: behavioral, cognitive, emotional, and physical. Of these dimensions, physical and cognitive are most closely related to driver safety and performance. Physical fatigue includes attributes such as tiredness and lethargy, whereas cognitive fatigue includes attributes such as impaired alertness and decreased concentration (Wise, et al., 2019).

Platooning could pose additional challenges to the truck driver, whether they are in a leader or follower position (Calvert, et al., 2018). These challenges drive the need for additional research to inform the design of platooning technology, displays, and policies. While research is being done in the area of platooning safety, much of the empirical research is being conducted using driving simulators as opposed to field studies (e.g. Lee, et al., 2018), or evaluating trailing drivers in a platoon as opposed to lead drivers (e.g. Heikoop, et al., 2017).

Objective:
The objective of this portion of the study is to quantify vigilance, mental fatigue, and physical fatigue of the lead platoon driver over time. This research is motivated by the increased responsibilities of the lead driver when operating with automated follower vehicles. The results will be used to inform work schedules, in-cabin interventions, and display designs to maintain driver effectiveness.

Methods: Lead platoon drivers will be studied in a closed-system experiment at the National Center for Asphalt Technology (NCAT) test track at Auburn University, as well as field test using rural highways in Alabama and Mississippi. During the driving task, the truck driver will not have any in-cab displays regarding the trailing vehicles, nor will the driver receive any alerts or interventions for fatigue and vigilance. This will allow us to baseline vigilance and fatigue for platooning drivers, and identify areas in need of improvement. A mixed-methods study design will be employed to quantify vigilance, mental fatigue, and physical fatigue. All qualitative measures (e.g. surveys, interviews) will take place when the driver is out of the truck cab (e.g. before/after a drive, during a break). All quantitative measures (e.g. eye movement, posture) will be collected continuously during each drive trial. Table 1.5 presents an overview of the measures that will be collected during both the controlled (test track) and field (highway) studies.

Trial Phase	Measures
Pre-Drive and Breaks	Brief Psychomotor Vigilance Task (PVT-B) Stanford Sleepiness Scale (SSS) NASA-TLX Questionnaire Maximal Voluntary Isometric Contraction (MVIC) of Neck and Upper Extremity Muscles
Drive	Eye Movement Neck and Upper Extremity Posture Neck and Upper Extremity Muscular Exertion and Fatigue Seat and Back Pressure Heart Rate
Post-Drive	PVT-B SSS NASA-TLX Questionnaire MVIC of Neck and Upper Extremity Muscles Semi-structured Driver Interview

Table 1.5- Measures for driver fatigue and vigilance

Vigilance will be measured using the brief psychomotor vigilance task (PVT-B). In this test, participants respond to a visual stimulus that randomly appears on a screen, and reaction time is measured. The brief form of the test that will be used lasts three minutes. The PVT has been used successfully to measure vigilance for driving tasks. The semi-structured driver interview after the drive is complete will be used to capture the driver's perspectives on the platoon driving task, including information and task needs.

Mental fatigue will be measured using the Stanford Sleepiness Scale (SSS) in concert with the measurement of mental workload using the NASA-TLX questionnaire. These measures have been used successfully in driver fatigue research and provide valid subjective measures of fatigue. For objective measures of mental fatigue, we will rely on the tracking of driver eye movement during the driving task. Multiple eye movement measures will be evaluated, including pupil diameter, number of on-road fixations, fixation duration, blink frequency, blink duration, closure duration, and PERCLOS (percentage of eyelid closure over the pupil). This data will be collected using ADAM. The evaluation of eye movements to quantify mental fatigue in drivers has been successful in past studies.

ADAM will provide a comprehensive Driver Monitoring System (DMS) utilizing both open and closed loop techniques to provide driver cognitive performance measurement data. In addition, ADAM's DMS will incorporate existing DMS functionality such as driver drowsiness monitoring, postural position sensing, and head and eye tracking. Along with the research team's analysis of the raw eye tracking movement data collected during the driving task, ADAMs proprietary software will provide additional information about the personalized cognitive performance data for the driver. Multiple eye movement measures will be evaluated, including pupil diameter, number of on-road fixations, fixation duration, blink frequency, blink duration and closure duration. This data will be collected using and automotive Driver Facing Camera (DFC) and Electronic Control Unit (ECU) together with on-board data logging and storage capabilities.

Additionally, ADAM's software will provide progressive data to create a profile of the drivers baseline for cognitive capacity, in real-time this measure can be taken to establish the deviation from the baseline. This allows a threshold to be set where a certain percentage of deviation from the baseline can be considered as a means of providing a sophisticated driver warning system. The intent of this feature of the ADAM technology is detect severe cognitive impairments (which may be due to alcohol or substance abuse, or even extreme sleep deprivation) and provide a driver capable/incapable warning.

Physical fatigue will be quantified by neck and upper extremity posture, muscular exertion levels assessed using electromyography (EMG) of the neck and upper extremity muscles, seat pressure differences in both seat pan and back rest, as well as using heart rate monitoring for variability. These measures, specifically the EMG measures and heart rate variability (HRV) have been successfully used in driver fatigue research. To assess neck and upper extremity posture, video of the driver from the lateral aspect (right side of the driver) will be captured and used with MaxTRAQ biomechanical software (Innovision Systems, Inc., Columbiaville, MI) to quantify neck flexion/extension and right shoulder and elbow flexion/extension angles. Kinematic analysis of joint angles over the duration of the drive will be quantified to identify percent of time in extremes of flexion/extension angles. Muscle activity from right and left anterior deltoid (AD), upper trapezius (UT), biceps brachii, and splenius capitis (SC) will be collected during the drive using an 8-channel Noraxon DTS wireless EMG system (Noraxon, Scottsdale, AZ). Dual bi-polar electrodes will be placed on the muscle bellies of each muscle and muscle activity recorded during 3 trails of 3-second maximal voluntary isometric contraction (MVIC) of each muscle prior and after the drive and during the drive in 10-minute increments of the drive duration. To identify seating posture and fatigue, two FSA 4.0 (Manitoba, Canada) pressure mats will be used to quantify seat pressure in mmHg with one placed on the seat pan and the other on the back rest. Seat and back pressure mapping associated with ischial tuberosity and mid-back will be continuously measured throughout the drive duration at 5 Hz. Mean average and maximum seat pan and seat back pressures will be quantified. Additionally, heart rate during the drive will be measured using a heart rate monitor (Polar, Bethpage, NY) and measures of maximum, minimum, range and HRV will be used to quantify the physiological measure of the workload.

Examination of Support to AFTP Platoon Lead Driver via Smart Connected Infrastructure at Merge Points

At Auburn University, we want to examine merging efficiency when a platoon driver has advance I2V information about vehicles entering the highway via on-ramps – traveler information messages (TIMs) communicated to the trucks from road-side units (RSUs). We postulate that this information will be much more important to a Automated Follower platooning than one in which a human rear truck driver can adapt to traffic.

To created a connected V2X environment, UM-Dearborn designing and fabricating a RSU trailer will be duplicated and stored locally at other team member locations. The trailer will have a 20' collapsible telescoping mast on which will be mounted a time-of-flight (ToF) sensor (infrared/radar) to detect the presence of vehicles on the on-ramp. Also mounted on that mast is an RSU, that will broadcast "vehicle entering" information as a TIM.

Our physical testing and simulation involves the ability of the AFPT to operate safely with and without this advance TIM. We are not aware of this type of fine-grained information being created and sent to vehicles to help make control decisions on acceleration/deceleration/lane-change.

1.6.3. Approach to Address Legal, Regulatory, Environmental, or Other Obstacles Due to Federal, State, or Local Requirements

The proposed demonstration does not require exemption from the Federal Motor Vehicle Safety Standards (FMVSS), Federal Motor Carrier Safety Regulations (FMCSR), or any other regulation.

1.6.4. Possible Need for Exception Under the Buy American Act or Terms of NOFO Clause Section F, Paragraph 2.J. Entitled "BUY AMERICAN AND DOMESTIC VEHICLE PREFERENCES"

The proposed demonstration does not require an exception under the Buy American Act or an exception to the terms of the NOFO Clause at Section F, Paragraph 2.J. entitled BUY AMERICAN AND DOMESTIC VEHICLE PREFERENCES. Per the clause, demonstration activities will be compliant with the Buy American Act, 41 U.S.C. §§ 8301–8305, as implemented at 48 C.F.R. Subparts 25.1–25.2; and the requirement that the Recipient not expend grant funds to purchase a motor vehicle unless the final assembly of that vehicle occurred in the United States (no vehicles will be purchased within the proposed demonstration).

1.6.5. Commitment to Provide Data and Participate In the Evaluation of Safety Outcomes and Other Arenas

The Auburn team commits to provide data and participate in the evaluation of the safety outcomes of proposed activities, as well as note measures of effectiveness in other arenas, such as mobility. Data collection and evaluation of safety aspects is core to our approach. Mobility factors with regard to AFTP merging and traffic interactions represent a major part of the proposed work.

1.6.6. Approach to Risk Identification, Mitigation, and Management

Risk identification, mitigation, and management will be core to all activities, with IS4S taking project -wide responsibility. Embedded in the work tasks are specific functional safety analyses as well as creation, implementing, and regularly updating of a Risk Management and Mitigation Plan, based on extensive IS4S experience in this area. Risk is also being minimized by utilizing knowledge and expertise from previous on-road demonstrations already conducted by the team as discussed previously. Additionally, on-track testing to shake out system readiness will contribute significantly to risk mitigation of the proposed demonstrations.

1.6.7. Approach to Contribute and Manage Non-Federal Resources (cost share) Proposed for the Demonstration Implementation and Evaluation

Auburn, ADAM, Mississippi State, and University of Michigan Dearborn have all committed non-federal resources to the project. The cost share is provided in terms of faculty release time during the academic year as well as providing cost to cover engineering support for the project. Additionally, Auburn University is contributing salary for faculty, graduate students, as well as money to automate one test truck. These cost share items are documented in the budgetary information. Additoinally, Auburn University is contributing additional resources of investment not formerly included in cost share including a new autonomous vehicle building, a semi-truck for NCAT operations, and track time for the truck operation. It is the goal of this project that one truck is operating continuously at the NCAT test track by the end of the project.